



Review

Phenanthrene biodegradation by sphingomonads and its application in the contaminated soils and sediments: A review



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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs), a class of hazardous chemicals ubiquitous in many ecosystems, are of great concern due to their potential toxicity, carcinogenicity, teratogenicity, and mutagenicity. Phenanthrene, a low-molecular-weight hydrophobic PAH, binds to particulates in the soil and sediments, thus inhibiting biological uptake. In such PAH-contaminated environments, some well-adapted microorganisms, such as the sphingomonads (belonging to the Family *Sphingomonadaceae* in α -Proteobacteria) can degrade phenanthrene, whether in isolation or cometabolized with other PAHs. Some of the members of sphingomonads, consisting of the *Sphingomonas*, *Sphingobium*, *Novosphingobium*, and *Sphingopyxis* genera, have adjusted well to contaminated soil environments compared to most bacterial genera that degrade PAHs. This is manifested in phenanthrene, which has been found to induce strong up-regulation of extradiol cleavage pathway enzymes in sphingomonads with similar gene and enzyme homology to *Sphingobium yanoikuyae* B1, where enzymes like ring-hydroxylating dioxygenase, putative biphenyl-2,3-diol 1,2-dioxygenase, and catechol 2,3-dioxygenase are encoded by *bphA2CA1c*, *bphA1[a-e]*/*A2[a-e]* (which both require *bphA3bphA4*) and *bphC* genes, respectively. With *meta*- and *ortho*-cleavage pathway routes, this has made sphingomonads a well-adapted group of microorganisms. This review will focus on taxonomic, autecological and genetic features of sphingomonads which impact on their ability to metabolize phenanthrene at different rates and under different conditions.

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1. Introduction

Polycyclic aromatic hydrocarbons (PAHs), a class of toxic, fused-ring pollutants (Blumer, 1976; Supaka et al., 2001), have accumulated in the environment as a result of human activities. Globally, there has been a vast increase in environmental pollution over the last century since it became an important issue after the industrial revolution in the late 1940s. The current situation, exacerbated by anthropogenic sources like industrial and agricultural development, population growth, and urbanization, has led to the neglect of the environmental consequences of releasing polyaromatic hydrocarbons into the environment. The increase in fused benzene rings in PAHs reduces their solubility and increases the hydrophobicity, which, therefore, increases persistence and pollution in the environment. With soil ecosystems being fragile in nature and exposure to chemical contaminants like PAHs expediting serious environmental concerns, the need for efficient remediation strategies is imperative. Some of the physicochemical remediation methods like solidification/stabilization, chemical oxidation among others, are expensive and ineffective (Wilson and Jones, 1993; NRC, 1994), as some of them may transfer the pollutants from one phase to another, thus not actually removing the PAHs from the soil. On the other hand, microbial bioremediation has been shown to be effective in remediating environments contaminated with low-molecular-weight PAHs (LMW-PAHs) (Banerjee et al., 1995; Kästner and Mahro, 1996; Mueller et al., 1991); however, they are generally recalcitrant to microbial degradation of high-molecular-weight PAHs (HMW-PAHs) (Cerniglia, 1993; Erickson and Mondello, 1992; Park et al., 1990). For successful microbial remediation of PAHs to occur in soils and sediments, there needs to be a greater understanding of the processes involved and the factors enhancing degradation of PAHs.

Most of the isolated degradative microbes from PAH-contaminated soils and sediments are from polluted environmental matrices, thus showing a general preference of pollution as a precursor to the discovery of these adaptive microorganisms. Some of these bacterial species found in PAH-contaminated terrestrial environments are members of the sphingomonads (which belong to Family *Sphingomonadaceae*). The members of this catabolically versatile group are capable of degrading these recalcitrant compounds. Phenanthrene, as one of the classified priority pollutant PAHs by the US Environmental Protection Agency, has been extensively used as a model for studies of microbial degradation by these organisms, via the cometabolic oxidation and direct oxidation. The subject of this review is primarily based on the microbial degradation of phenanthrene by sphingomonads, their catabolic versatility towards this, as well as the degradation parameters involved and other current research into this bacterial group.

2. Physical properties, production, occurrence and uses of phenanthrene

PAHs refer to hydrocarbons composed of multiple fused (two or more) benzene rings in planar, angular or clustered arrangements that contain only carbon and hydrogen. They occur as colorless, white/pale yellow solids with low solubility in water, high melting, and boiling points, as well as vapor pressure decreases (Johnsen et al., 2005). These features demonstrate why remediation of PAH-contaminated soils is important; they are cytotoxic, teratogenic, mutagenic and carcinogenic, and they persist in soils and sediments (Cerniglia, 1993; Habe and Omori, 2003). Phenanthrene (C₁₄H₁₀; molecular mass of 178.22, as cited in ATSDR, 1995), a model PAH, contains three fused benzene rings in an angular arrangement. Other examples include naphthalene, anthracene, chrysene, pyrene, and benzo[a]pyrene.

Most PAH contamination in soils is found around wood treatment plants in which creosote is used, former gas production plants, asphalt production plants, petroleum refining plants and waste incineration plants (NRC, 1983; Supaka et al., 2001). PAHs are formed naturally during thermal geological processes, and during the burning of vegetation in forests and bush fires (Blumer, 1976; Juhasz and Naidu, 2000). In sediments, PAHs contaminants display poor water solubility properties, forming nonaqueous phases or films that pose several problems primarily due to their binding capacities. These polyaromatic compounds block sunlight from penetrating into the mangrove sediments and act as a barrier between the water and air phase, thus preventing adequate gas exchange and creates an anoxic and highly toxic environment. Most of these polyaromatic hydrocarbons are common pollutants in soils and sediments in industrialized countries, especially in PAH-contaminated surface soils, sediments and solid waste sites in high concentrations (Moody et al., 2001).

Phenanthrene is an LMW-PAH, which is isomeric with anthracene in its chemical structure and appears as a white/yellow crystalline substance. Phenanthrene is a major constituent of coal derivatives and fossil fuels (Supaka et al., 2001). A tricyclic PAH, it is a primary product that originates from the combustion of organic materials (Young and Cerniglia, 1995). It is used as an intermediate in the manufacture of phenanthrenequinone in pesticides, plastics manufacturing and the production of diphenic acid, as well as an intermediate in the production of resins (dyes). Other industrial uses include the making of bile acids, cholesterol, and steroids. These physical properties make phenanthrene industrially useful in many aspects. Environmentally, it does not present a health risk to humans, unlike the HMW-PAHs, but is toxic to fish and algae, making it 1 of 16 PAHs on the list of priority pollutants listed by the USEPA (Heitkamp et al., 1988). Its toxicity and persistence make this tricyclic hydrocarbon an environmentally crucial in bioremediation studies.

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